Report 17: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines

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Abstract

This report highlights work done on a project intended to lower the cost of environmental compliance and expedite project permitting for Exploration and Production (E&P) operators by identifying, developing, testing, and commercializing emissions control and monitoring technologies. Promising technologies have already been identified and developed. Current work focuses on testing these promising technologies. Specifically, several technologies are being tested in the laboratory for application to lean-burn engines or fully characterized on-site for use with rich-burn engines. Upon completion of these tests, the most cost-effective and robust technologies will be tested in the field and commercialization will ensue.

During this quarter, progress in laboratory testing for lean-burn engines was limited by maintenance issues on the KSU Ajax DP-115. The difficulties that required maintenance to be performed will likely require that the 180 psig prototype valve be tested in the future, if possible. The maintenance was performed, and it is expected that the Ajax will be available for testing in the coming quarter.

Although laboratory testing was slowed as a result of maintenance issues, progress in experimental characterization of technologies has been significant. NSCR systems will be characterized as applied to rich-burn engines on-site. This characterization will ensure high-quality data in final field testing on rich-burn engines and is considered to be essential, despite that the work requires the delay of official field testing until 2008. Many preliminary and administrative tasks have been completed, including initial site selection, official proposal submittal, and beginning a process to approve necessary changes to installed field engines.

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Introduction

The objective of this project is to identify, develop, test, and commercialize emissions control and monitoring technologies that can be implemented by exploration and production (E&P) operators to significantly lower the cost of environmental compliance and expedite project permitting. The project team will take considerable advantage of the emissions control research and development efforts and practices that have been underway in the gas pipeline industry for the last 12 years. These efforts and practices are expected to closely interface with the E&P industry to develop cost-effective options that apply to widely-used field and gathering engines, and which can be readily commercialized.

The project is separated into two phases. Phase 1 work, which has already been completed, established an E&P industry liaison group, developed a frequency distribution of installed E&P field engines, and identified and assessed commercially available and emerging engine emissions control and monitoring technologies. Current and expected E&P engine emissions and monitoring requirements were reviewed, and priority technologies were identified for further development. As a part of Phase 2, the identified promising technologies will be tested on a laboratory engine to confirm their generic viability. In addition, a full-scale field test of prototype emissions controls will be conducted on at least ten representative field engine models with challenging emissions profiles. Emissions monitoring systems that are integrated with existing controls packages will be developed. Technology transfer/commercialization is expected to be implemented through compressor fleet leasing operators, engine component suppliers, the industry liaison group, and the Petroleum Technology Transfer Council.

Forecasts of future U.S. natural gas demand of 30 trillion cubic feet (Tcf) /yr by 2015 require 36% production growth from 2001 levels. Demand growth will be addressed by both conventional gas and coal-bed methane. The majority of the increase in conventional gas production is expected from three primary areas: Offshore Gulf of Mexico, Rocky Mountains, and Canadian imports. Mature basins in the Southwest and Mid-Continent areas will also contribute to the total domestic supply, and maximizing their output will be necessary to meet the aggressive 30 Tcf gas demand target.

Oil and gas production operations in the United States face a wide variety of environmental regulations that are imposed by multiple, sometimes overlapping, jurisdictions. In particular, onshore production must grapple with existing and emerging regulations that address National Ambient Air Quality Standards for ozone, fine particulates, and NO_2, regulations regarding acid deposition and regional haze, and pending air toxics regulations, all of which will limit emissions from compressor engines. NO_X and formaldehyde will be the likely focus. The scope of these regulations will include the assessment of the need for emissions controls on the wellhead and field gathering reciprocating engine-driven compressor and pumping equipment that is ubiquitous in E&P operations. Current estimates are that approximately 15 million horsepower are presently operating in upstream production applications (Hanover Compressor Company 2001 10-K Annual Report filing). At an average size of 250 HP, this implies a total E&P fleet of 60,000 engines.

Though in many oil and gas production areas the air shed emissions inventory is dominated by coal power plants, regulatory agencies continue to pursue incremental reductions in total pollutant loading. Reciprocating engines have been identified as a meaningful source category. This is evident in Federal and State actions, as well as Environmental Impact Statements associated with new development. These engines are used to produce electricity for a leasehold, compress and re-inject natural gas for increased oil production, compress natural gas so that it can be delivered to local gathering systems that ultimately feed into gas transmission pipelines, and drive smaller-load equipment such as pump jacks.

At present, the region with the greatest confluence of emissions concerns for small IC engines is the Rocky Mountain and Intermountain West area. In these regions, significant concerns about regional haze control accelerated the implementation of NO_X and fine particulate regulations that are only pending in many other producing areas. However, the incremental adoption of regulations state-by-state, as well as the proximity of many remote production areas in the Southwest to National Parks and Class I Wilderness Area (which are protected air-sheds) may likely stimulate aggressive compressor engine controls in that and other production regions, as well. Finally, the East Texas and Louisiana regions are subject to conventional ambient ozone concerns, and have promulgated strict NO_X controls for reciprocating engines. In addition, EPA will propose regulations in 2006 for final adoption in 2007 that will address smaller IC engines in all applications throughout the U.S. These rules include a New Source Performance Standard for IC engine, as well as air toxics standards for: (1) area sources (i.e., engines at smaller facilities), and (2) Engines 500 hp and smaller at major sources.

Oil and gas production from <u>all states</u> will be required for the U.S. to meet the expected 30 Tcf/year gas demand and to minimize the ongoing slide in domestic oil production, and impediments to production that are created by air quality permitting must be alleviated through focused R&D efforts.

Gas compressor operations are an essential element of oil and gas production. Increased emissions constraints on compressor operations affects oil and gas production in four distinct ways:

- The <u>length of time to obtain an emissions permit</u> is increased as multiple jurisdictions evaluate the effects of various pollutants and attempt to define a mutually acceptable permit level for a given engine. Furthermore, permitting may become impossible when performance targets for application of emission controls to small engines are inappropriately established at levels that are technically infeasible or only achievable based on expenditures well in excess of forecasts of the implementing agencies.
- The capital and operating costs of compressor engine operation are increased as this <u>equipment is physically modified and/or operated differently</u> to comply with the air permits.
- The capital and operating costs of compressor engine operation are increased when <u>expensive and maintenance-intensive continuous emissions monitors are required</u>, as is the case in parts of California. In many settings, the cost of this monitoring exceeds the cost of NO_X control.
- Compressor operators may be forced to <u>limit the annual hours of operation</u> to avoid exceeding a fixed annual ceiling on allowed emissions.

Each of these situations impedes oil and gas production by:

- Deferring the start of wellhead production, thereby increasing the general business risk in current price-volatile markets and increasing the carrying costs of various lease and development fees,
- Directly increasing the cost of compression services used at the wellhead,
- Artificially limiting the annual take from a well due to constrained operations.

The net effect is reduced oil and gas production for a given cost within a fixed time period. Multiplying this through thousands of production sites will most certainly have a significant negative impact on the ability of U.S. operators to meet domestic energy demands, and on the general productivity of the U.S. hydrocarbon resource base.

In addition, application of controls may result in emissions tradeoffs that can result in other deleterious environmental effects if not properly considered. These issues may be exacerbated by presumptions of technology performance that have not been proven for the engine sizes or operating applications present in oil and gas operations.

These economic and operating burdens to oil and gas operations can be reduced through a focused effort to develop cost-effective retrofit components, engine combustion controls, and engine performance monitoring options. The proposed project will significantly improve the cost-effectiveness of implementing NO_X and formaldehyde controls and monitoring on compressor engines, while characterizing emissions tradeoffs – thus ensuring that compliance with air regulations does not prevent oil and gas operations from achieving their maximum productivity at competitive production costs.

Basis of the Project

This project draws heavily on the experience gained from the interstate gas pipeline industry's experience with NO_X emissions reductions, and their efforts to develop cost-effective options for extensive deployment throughout their systems. A number of gas pipelines faced EPA statutory deadlines in 1994/1995 to achieve and certify dramatic reductions in compressor engine NO_X emissions across a very wide range of ageing and diverse, but critical, equipment. Even though typical pipeline reciprocating compressor engines range in size from 600 HP to 8,000 HP and are largely two- and four-stroke cycle integral compressors, there is some commonality in equipment types and operational concerns with the wellhead and gathering facilities under study in this project. Beginning in 1990, the pipeline industry embarked on a comprehensive R&D program that targeted significant (50%+) reductions in the cost of NO_X controls without any significant engine performance compromises. All of the technologies developed had to be field-retrofitable and commercially-supported. That program was a significant success and created a number of technical options that allowed up to 80% NO_X reductions in a cost-effective and operationally-acceptable manner. The individuals involved with this current project were key participants in that prior pipeline NO_X and formaldehyde reduction program.

The gas pipeline emissions control technology development effort was instructive in that it employed the following six distinct phases of activity, each of which was necessary for success:

- Obtain an industry consensus for

  - specific engine types and models on which to focus development efforts,
  - installed cost targets,
  - realistic emissions levels to be achieved under all operating conditions.

- Develop an inventory of installed horsepower to confirm initial industry guidance and to create a useful tool for impact analysis;

- Create a coordinated, core team of engine technologists, regulatory experts, and industry representatives to ensure that engine design issues, regulatory drivers, and practical operating considerations always were addressed simultaneously;

- Aggressively field test component and controls developments;

- Characterize the fundamental relationships between engine operating parameters and exhaust emissions so that accurate, non-instrumented emissions monitoring systems could be deployed; and

- Transfer technology results to organizations with an existing presence in the industry so that equipment could be provided on commercial terms, with emissions guarantees, and supported on an ongoing basis.

This project followed a similar broad outline with the expectation that the end product is a set of cost-effective emissions control and monitoring options that can be applied to a wide range of compressor engines in common use in oil and gas production. Operators will enjoy reduced costs of compliance, greater permitting certainty, reduced costs of emissions monitoring, and possible improved compressor performance due to improved combustion stability. All of this will sum to increased production as wells are brought online more rapidly, compression equipment is run harder and longer to facilitate increased production, and lifting cost savings are reallocated toward additional resource base development.

Controlled Testing on KSU Ajax DP-115

Controlled tests are conducted on the Ajax DP-115 at Kansas State University to address a series of upgrades intended to improve emissions. The DP-115 is a mature two-stroke cycle lean burn (2SCLB) engine, typical of those found at gathering sites. While many technologies have already been tested, more remain. Progress in controlled testing during this quarter was limited due to engine maintenance issues. The difficulties that called for maintenance will likely require the 180-psig prototype fuel valve test to be repeated, if possible.

At the end of the last quarterly report, concerns were raised by the failure of some of the data to aggregate into the expected speed lines. Upon further examination of the data and comparison with earlier data, it was determined that the average peak pressure was quite low. Specifically, average peak pressure in the August tests ranged from 200 psia to 300 psia, whereas tests using a similar mid-pressure fuel valve in May had average peak pressures near 400 psia. It was determined that the low average peak pressure was not a result of low combustion pressure, but rather a result of frequent misfiring, as shown in Figure 1.

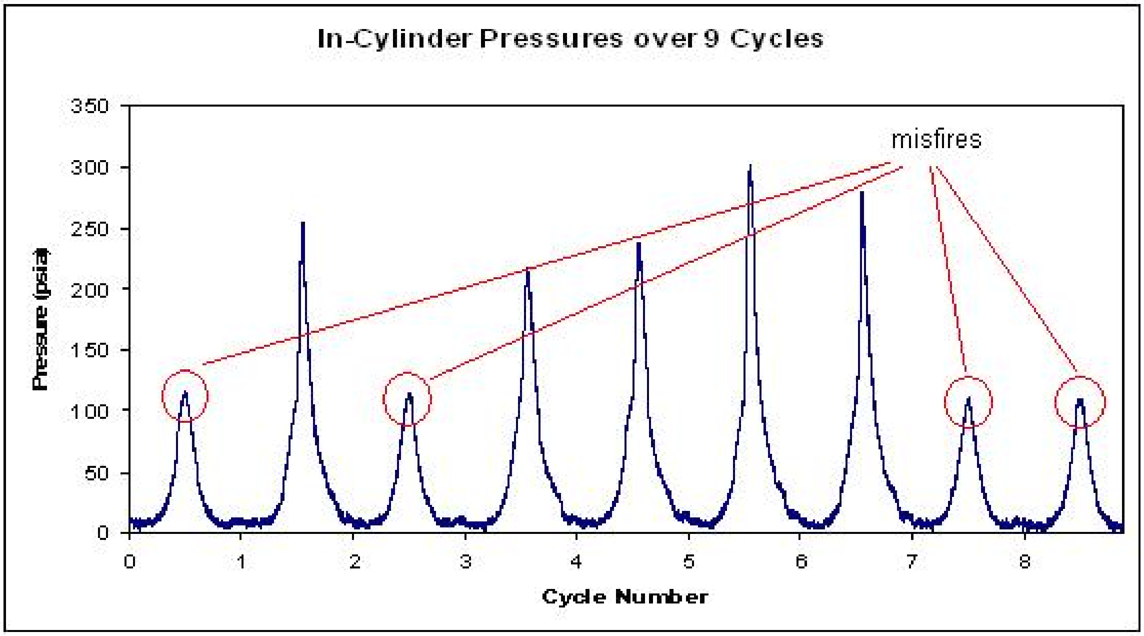

Figure 1. Low average peak pressure results from frequent misfiring.

Intensive trouble-shooting of possible problem areas, including the ignition system, the fuel-injection system, and the cylinder region, indicated that misfiring was a result of low compression pressure. Compression pressure can be measured by finding the peak pressure as the engine comes to a stop once the fuel supply has been stopped. Although the expected compression pressure for an Ajax DP-115 ranges from165 to 190 psia, as indicated by an Ajax internal quality control document, measurements on the laboratory engine were only around 110 psia. No significant problems were found in the other engine systems.

Between May, when the engine ran as expected, and August, the combustion conditions had changed significantly for the worse, apparently caused by low compression pressure. By comparing the cycle-to-cycle peak pressures and the average peak pressures for various data runs, as well as compression pressure where available, it was determined that combustion before mid-June was good, and combustion after that was unsatisfactory. The change took place after two major maintenance events. First, a brief overload condition in mid-June caused the head gasket to leak. While replacing the head gasket, the old head, which was showing concerning corrosion around the spark plug ports, was replaced as well. Expert technicians at Ajax believed that the most likely cause of low compression pressure was gasses from the cylinder escaping past the piston rings during compression, perhaps caused by softening of the piston rings during the overload event in June (Pate, 2006). Another possibility was that the new head on the Ajax was somehow larger than the old, increasing the clearance volume.

The piston rings were changed, as suggested by the Ajax technical experts. Because the engine head needed to be removed in order to change the piston rings, the volumes of the two heads were compared, and were found to be sufficiently close in volume that the small difference could not account for the difference in compression pressure. Although the engine has not yet been tested since the piston rings were replaced, the research team considers it likely that the problem has been fixed.

Unfortunately, because the mid-pressure fuel valve tests were undertaken with the engine in poor operating condition, the results cannot be used to compare the promise of that technology to the others tested. Trends within the mid-pressure fuel valve data set, however, are likely indicative of trends that occur under excellent operating conditions with the same valve. If possible, the mid-pressure fuel valve tests will be replicated to allow the technology to be compared to other options and confirm the trends within the data set.

NSCR Characterization

Among operators and regulators, NSCR systems have been the most trusted method for emissions reduction on rich-burn engines. This led the research team to consider them to be the obvious technology to use for emissions reduction in field testing of rich-burn engines. However, the results of studies conducted by McGivney (2006) and Arney (2006) indicate that current NSCR systems are not sufficient at very low emissions levels or for continuous control as ambient conditions change. Emissions levels and conditions where an NSCR system can remain a robust, continuous solution for a rich-burn engine will be determined during an industry-funded project to determine the capability of NSCR systems in the Four Corners region of New Mexico and Colorado on actual field engines. Although this work will delay official field testing until 2008, it will provide the groundwork necessary in order to ensure high quality data from the field tests on rich-burn engines. Significant progress toward starting this project was made during this quarter.

A major step toward beginning work is to gain official approval from all parties. An official project proposal was submitted to industry participants in late October, and final budgetary details are in the process of being worked out. Additionally, members of the research team traveled to the DOE NETL Tulsa office to present information regarding the work planned for the Four Corners region. Although this work deviates from the original plan for the project and represents an overall delay in completion, it was seen as adding considerable value to the overall project.

Additionally, success was met during a visit to the BP Farmington Operations Center in New Mexico, where initial test sites will be. While in Farmington, the research team visited several potential test sites, and picked out two test sites at accessible locations with appropriate engines. One engine, a CAT 3406 already has a catalyst system, which will need an upgrade that Miratech has agreed to donate. The other engine, a Waukesha 330, will need to have a catalyst system installed. The final engine to be tested will be a Compressco GasJack, but while many sites with such an engine are available, an ideal site still needs to be chosen. During this visit, the research team was also able to begin internal BP paperwork to allow for access to and changes at the proposed test sites, including additional instrumentation, photovoltaic cells to provide power, additional or upgraded catalyst systems, and storage for necessary equipment.

Conclusions and Future Work

This quarter, a problem was discovered in the KSU laboratory Ajax DP-115. Although this means data taken since July 2006 is not good enough to allow the research team to draw firm conclusions, the data presented in Report 15 is still valuable to see trends that occur while using the mid-pressure fuel valve. Additionally, the data proved very valuable in helping to recognize and solve the problem with the laboratory test engine. Maintenance performed on the engine should fix the problem and allow testing to resume.

Progress toward characterizing NSCR systems for rich-burn engines was significant. Although this work requires the official field testing to be postponed until 2008, the industry-sponsored project to characterize NSCR technology will give a robust basis to start that phase of the project. Many necessary administrative tasks were completed, including presenting an official proposal to participating companies, presenting the idea of integrating this externally-funded work into the existing project to interested parties at the DOE, selecting engines and sites where work will begin, and beginning the process to allow adding equipment to field engines for testing.

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